Atmospheric Moisture Content Near the Sea Surface Using Vaisala Rawinsondes

J. Vorrath

Purpose:

To use Vaisala rawinsondes to closely examine the moisture content of the lowest levels of the atmosphere.

Fundamental Issues and Importance for Navy:

In order to clarify the intent of this project, one of the first fundamental issues that must be addressed is what is meant by the use of the terms "lowest level" and "near" when referring to the atmosphere and proximity to the sea surface respectively. The primary area of interest for this experiment was the portion of the atmospheric planetary boundary layer either in contact, or near contact, with the sea surface. This was the layer immediately above the ocean that had a depth of only about 0.5 to 1.0 meters. As we will see when data collection is discussed, trying to make precise, effective observations so close to the oceanic planetary boundary layer was difficult.

Another fundamental issue is why we were interested in this thin layer, and what was the phenomenon we expected to see. At these defined lowest levels of the atmosphere, instinctively we would assume that moisture content would be very high. Due to the wind stress and turbulent mixing associated with the air-sea interface, the amount of moisture that is violently entrained into the atmosphere at this point should put the air either at, or near, saturation. Then, as we move slightly higher, and away from the near sea surface, we would expect to see moisture content drop significantly and equilibrate at a value associated with the air mass above.

In previous instances of this course, measurements were taken near the sea surface, of the evaporation duct, and of moisture content. Suspending a rawinsonde from the bottom a kite and then flying the kite from the fantail of the research vessel accomplished this. Enough slack was given to reduce the influence of the ship itself by putting the sensor well astern of the vessel, and then the kite was alternatively dipped near the surface and raised high. This was intended to give a profile of the lower 50 or so meters of the atmosphere. What was unusual about the results was that in all of these cases, the moisture levels at the lowest points of the flight were never seen to rise to near saturation. An evaporation duct was often sensed and humidity would increase as height in the atmosphere decreased, but there was no clear increase humidity to near 100% as we just stated would be expected just above the ocean.

The lack of this noted increase in moisture content as we near the surface of the ocean is an important consideration for the Navy, and researchers in general, which raises possible concern for several reasons. Since an extremely humid, moist layer was not found, even though we believe conceptually it should be there, this might indicate that the sensors used by scientists and the Navy for this purpose are inadequate. This would be a significant finding since rawinsondes have been used for decades in scientific research and in forecasting during Naval operations. If it is possible that this extremely moist layer is so thin that it could not be sensed, and therefore exists only in theory, it may change our understanding of the typical theoretical atmospheric profile.

With all of the above in mind, this project was undertaken to investigate and measure this elusive, extremely moist layer. It seemed the problem could be the sensitivity of the sensor, whether or not this extremely moist lowest level was actually present, or if measurements had in fact been taken close enough to the surface of the ocean. Since adequate accuracy of the sensor, to a certain degree, is an assumption that must be made in order to make useful measurements this could not be effectively investigated within the confines of this class. We had to rely on the calibration techniques of the Vaisala Corporation. The only way to know with certainty that this layer was present was to measure it, so the only question that remained to investigate was whether or not we had actually gotten close enough to the sea surface to effectively measure the rise in moisture.

Method:

During a seven-day period, 21 July 2003 to 28 July 2003, data was collected aboard the R/V POINT SUR. The first leg of the cruise involved departing from Moss Landing, California, proceeding to about 50 miles offshore and then turning south. Once offshore of San Luis Obispo, then vessel headed inland. The second leg of the cruise traveled north back to the Monterey Bay from San Luis Obispo, but tracked closer to the shoreline this time. During both the first and second legs, teams of students were taking atmospheric and oceanographic measurements as part of a 24hr watch bill. There were four instances in which measurements specific to this project were taken.

The primary atmospheric variables required for this project were relative humidity and specific humidity. Temperature also had to be measured and plotted as well, since we will see that it has a significant impact on relative humidity. Relative humidity is the amount of water vapor contained in a particular parcel of air divided by the amount of water vapor it is possible for that parcel to hold at it’s current temperature. Generally, it is given as a percentage of the level of saturation for a parcel. Relative humidity can vary either from a change in the amount of moisture in an air parcel or due to a change in the temperature of that parcel. For example, if the relative humidity of air is dropping, there is either less moisture present or the temperature is rising. Specific humidity is the mass of the water vapor in a parcel divided by the total mass of the parcel. It is given in g/kg and is independent of temperature, so it can give us a better idea of the true amount of moisture present in the atmosphere.

The sensors used to collect data during these measurements were Vaisala RS80 rawinsondes. Two types of this instrument were used, the Loran-C and Omega versions. Both of these models of rawinsonde are older than the Global Positioning System (GPS) variant currently in use, but were assumed to be accurate. Vaisala gives the resolution for its temperature sensor as 0.1ºC, with a reproducibility of 0.2ºC to 0.4ºC. For the relative humidity sensor, resolution is 1% with a reproducibility of <3%. The lag times for temperature and relative humidity are <2.5 seconds and 1 second respectively.

Using the method previously described, measurements of the near sea surface atmosphere were attempted using Vaisala rawinsondes attached to a kite. In order to obtain more accurate results for the lowest half-meter of the atmospheric planetary boundary layer, however, a new means of taking these measurements had to be devised. Professor Peter Guest devised a method by attaching a rawinsonde to the end of a pole, approximately 3 meters in length. From the deck of a ship, the pole was used to alternate between suspending the sensor in an “up” and “down” position above the sea surface. The “up” position was approximately 0.5 meters above the surface of the ocean and the “down” position approximately 3 meters above. This process allowed measurements very near the sea surface, and then slightly above that, to see how the moisture characteristics changed.

After making several measurements using this means of data collection, it became apparent that getting even closer to the sea surface itself might enhance the observation of moisture content. With this in mind, Prof. Guest made arrangements with the POINT SUR's engineer to man and launch the ship's Rigid Hull Inflatable Boat (RHIB). Aboard the RHIB students were able to use the rawinsonde/pole device to take the vital lowest level measurements just inches above the sea surface. As will be discussed in the results section of this paper, this tactic paid dividends.

One of the difficulties encountered while using this method of data collection was keeping the sensor dry and, thereby, taking accurate measurements. The humidity sensor on the RS80 is a delicate wire apparatus with a small protective cap, and was obviously not designed with this use in mind. Since observations were being taken so close to the sea surface, it was almost inevitable that instrument was accidentally, briefly submerged. When this happened during a reading, attempts were made to flush the device with fresh water and then dry it. Afterward, the readings seemed to return to normal so use of the mechanism continued. In addition to being completely submerged, the sensor was subjected to spray and possibly salt coatings that may have made performance difficult.

Upon the return of the students, the collected data was analyzed using several MATLAB methods provided by Prof. Guest. The rawinsonde data was loaded into the MATLAB working space as a '.mat' file using ldsonde_d3 (Guest, 2003). From there, a time series plot of pressure, relative humidity, temperature, and specific humidity for each of the four measurement periods were produced (Vorrath, 2003). In addition, vertical profiles of temperature and specific humidity were created for each rawinsonde (Frederickson, P., 1998-2000) (Jordan, M., 1996) (Guest, P.).

Results:

Using the aforementioned methods and graphs, the analysis of the collected data follows fairly naturally. The fluctuations in pressure, relative humidity, temperature, and specific humidity correlate to the times when the sonde was in either the “up” or “down” position. An increase in pressure and relative humidity theoretically denotes a lower height of the sensor, putting it in the most heavily moisture laden air just above the sea surface. The additional correlation of temperature change allows us to be sure that fluctuation in relative humidity are due to variations in the actual moisture content of the atmosphere and not due to heating or cooling of the air parcel. To reinforce this, specific humidity gives us another measure of the amount of moisture present in the atmosphere that is independent of temperature variation. Finally, the vertical profiles of specific humidity and temperature establish whether or not the observed atmospheric values are as expected when compared to a theoretical profile. It is also important to note while examining the following figures that the first two sondes were taken for the deck of the ship, while the third and fourth were taken from the RHIB.

As we examine the data from the first rawinsonde measurement (Figure 1.), a strong correlation between pressure (height) and humidity changes is not readily apparent. In once area, at approximately 750 seconds (denoted with a black oval), both of the humidity and the temperature readings seem to be exceptionally low and then oscillate excessively. This particular disruption was due to the submerging of the sensor in the ocean and then the subsequent cleaning with fresh water. After that, however, the readings seem to become more reliable, with only brief exceptions at 2750 and 3200 seconds (denoted with green ovals). This was due to moving the sensor to around the fantail of the research vessel while trying to locate a better place to take readings. At this point it is also interesting to note that the pressure never seems to settle at a specific

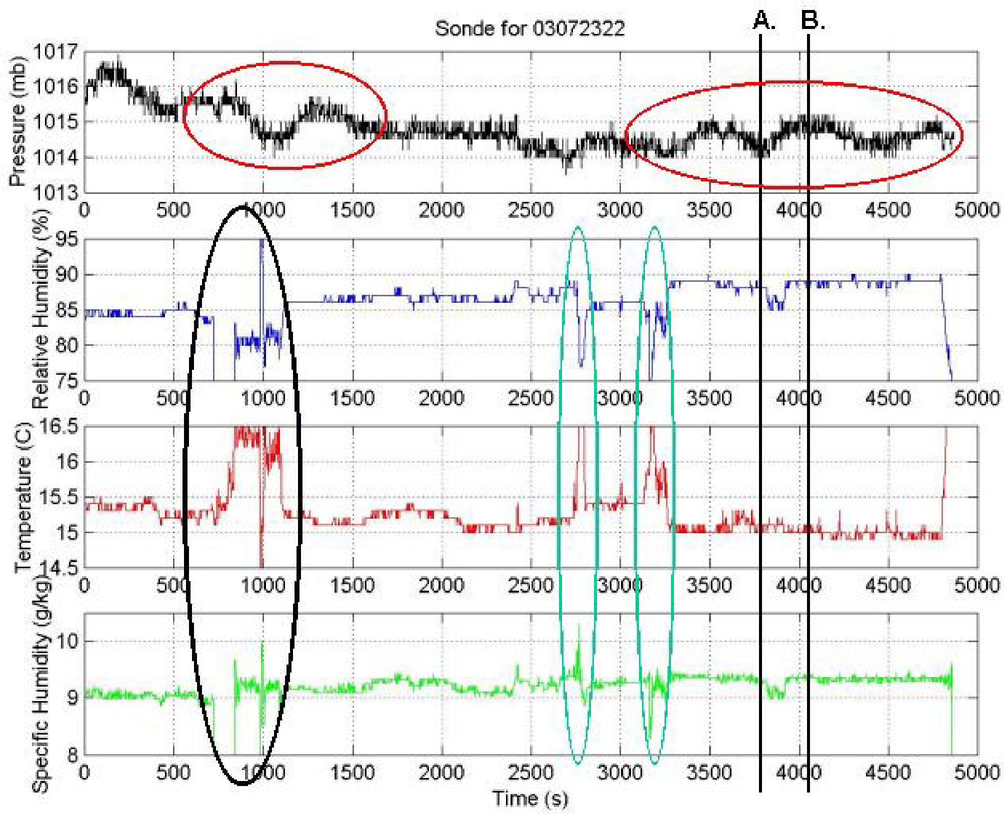

Figure 1. Rawinsonde data collected 23 July at 2003 at 22Z.

value. Between 500 and 1500 seconds and again between 3250 and 4500 seconds (highlighted with red ovals) we see slow, almost sinusoidal increases and decreases even though our sensor was held in either the "up" or "down" position for 5 minutes at a time. This is a significant observation and will be revisited later. For now, however, it sufficient to note that the changes in pressure as the sensor was lowered and raised did not register instantaneously, or even within 1 or 2 seconds.

Samples of the data obtained from this first collection point were more closely examined to see how spot observations compared to a theoretical atmospheric profile by height. One of the times examined was when the sensor was in the "up" position (Figure 1., line A.) and the other was when the sensor was in the down position (Figure 1., line

B.). The specific humidity and temperature values at these positions are shown plotted against a theoretical vertical profile of the atmosphere (Figure 2.). The profile was

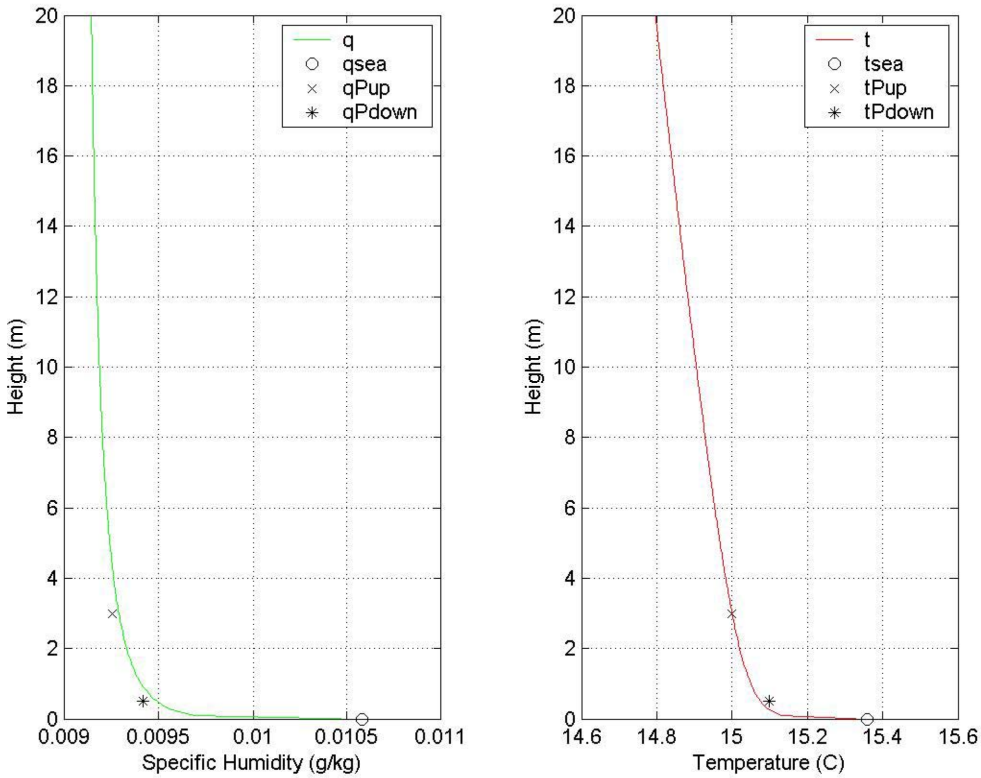

Figure 2. Vertical profiles of temperature and specific humidity calculated from Fig 1 input.

computed using the sea surface values (indicated using circles) and the "up" position values (denoted with an "x"). The slight difference between the "up" value and the plotted profile line was due to the use of slightly different specific humidity calculations, but is considered insignificant. The "down" position value (designated using asterisks) was the reading taken just above the sea surface. This value tells us whether or not that low level value matches the profile, and if that thin, moist layer is present. In this first reading we see that both the specific humidity and temperature values are very close to the theoretical values at these times. Thus, the moisture rich, near saturation air we would expect just above the sea surface is present, but only within a very thin layer less than half a meter deep.

As we examine the rawinsonde data from the second measurement period (Figure 3.), there are several observations we can easily make. The first is that in this data set

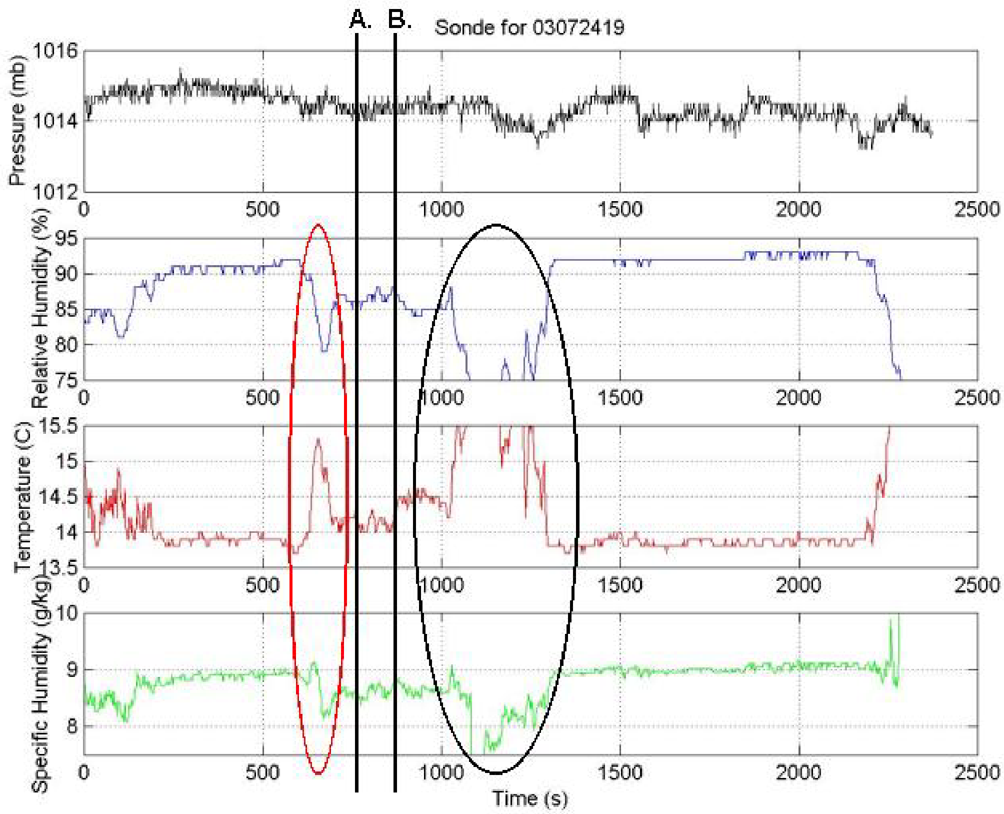

Figure 3. Rawinsonde data collected 24 July 2003 at 19Z.

there is only a very weak sinusoidal oscillation associated with the atmospheric pressure. It occurs in the second half of the data set, and is only vaguely recognizable. There are also two major periods where the data appears to be skewed, similar to what we saw from the first sonde measurements. One of these instances occurs approximately 600 seconds after the readings began and was due to a change in the ship's heading (indicated by red ovals). Stack gasses and other contaminating influences from the vessel caused a brief disturbance of the temperature and humidity measurements. There was a larger disruption approximately 1000 seconds into the data set (black oval). This was due to relocating the rawinsonde apparatus from the fantail to the forecastle of the POINT SUR. As we will see later when comparing these results with those from the RHIB, it is important to note that all of the data up to this point was taken from somewhere on the deck of the research vessel.

Since within this data set there was even less of a correlation between the chosen variables, points between the above mentioned disturbances, where the readings seemed to normalize, were chosen for vertical profiling. As with the first case temperature and specific humidity values were chosen in the "up" (A.) and "down" (B.) position, and then plotted (Figure 4.). Once again, the 0.5 meter specific humidity and temperature readings

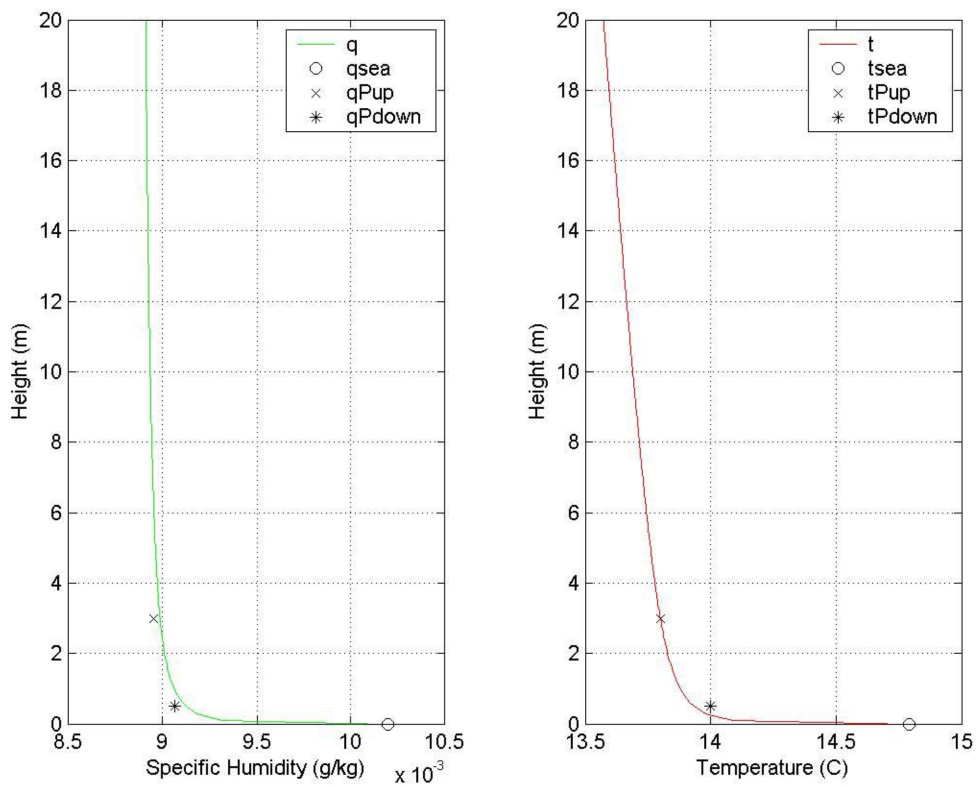

Figure 4. Vertical profiles of temperature and specific humidity calculated from Fig 3 input.

correlate very closely with the theoretical profile for the low level atmosphere. Again we see that there appears to be a very thin, moisture-laden layer that is restricted to a height of below 0.5 meters.

As we examine the third and fourth data sets that were collected, there is an important change in how the measurements were taken. The previous two sets had been taken from somewhere on the deck of the POINT SUR. For these last two sets, however, data was collected from aboard the ship's small RHIB. This allowed the students and the sonde to take readings from just above the sea surface. As we will see, this change in location had a powerful effect on the variables observed.

At first glance, the most striking difference between the third data set (Figure 5.)

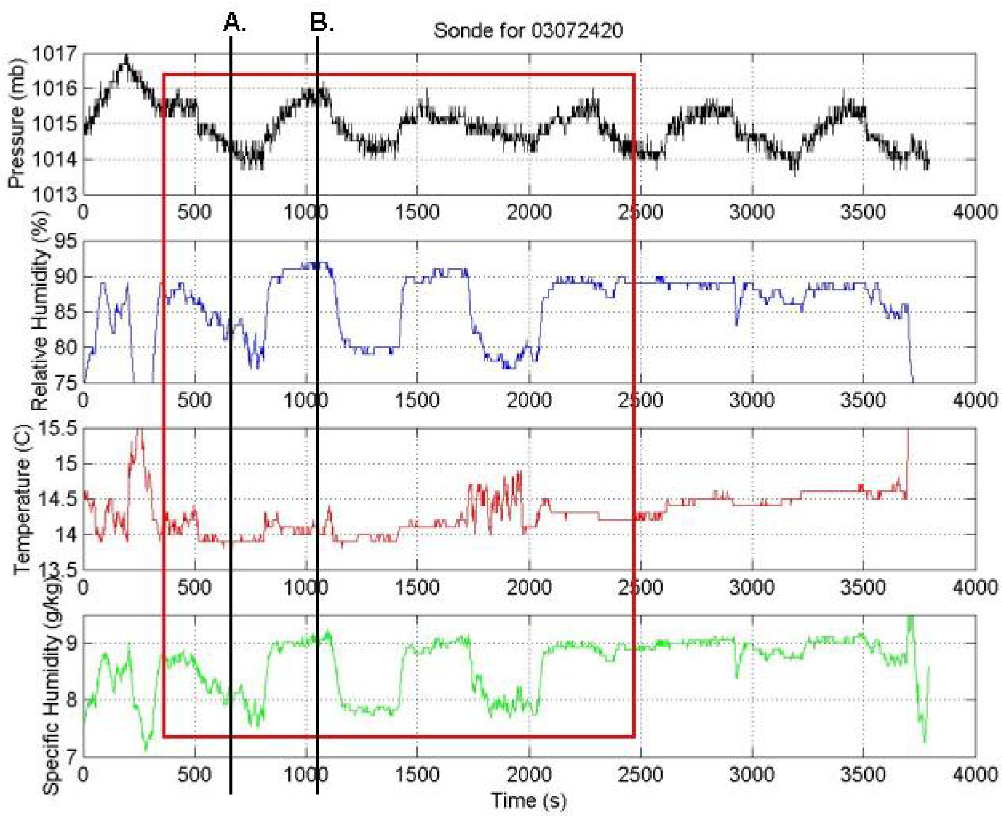

Figure 5. Rawinsonde data collected 24 July 2003 at 20Z.

and the previous two is the obvious tie between pressure and the humidity values. During the first half of the measurement set (red rectangle) there are related increases and decreases occurring between pressure, relative humidity, and specific humidity. We also note that, for the most part, temperature remains fairly constant. This indicates that the fluctuations in relative humidity are due to changes in the moisture content of the air, and are not due to temperature fluctuations. As the rawinsonde is lowered to just above the sea surface, the barometric pressure increases as do the relative and specific humidity. This seems to illustrate the “moistening” of the air as we near the very lowest levels of the atmospheric planetary boundary layer. This is further indicated when we see the opposite happen as the sonde is raised. Pressure, relative humidity, and specific humidity all decrease as height increases.

Again, two points are selected (A. and B.) to represent the “up” and “down”

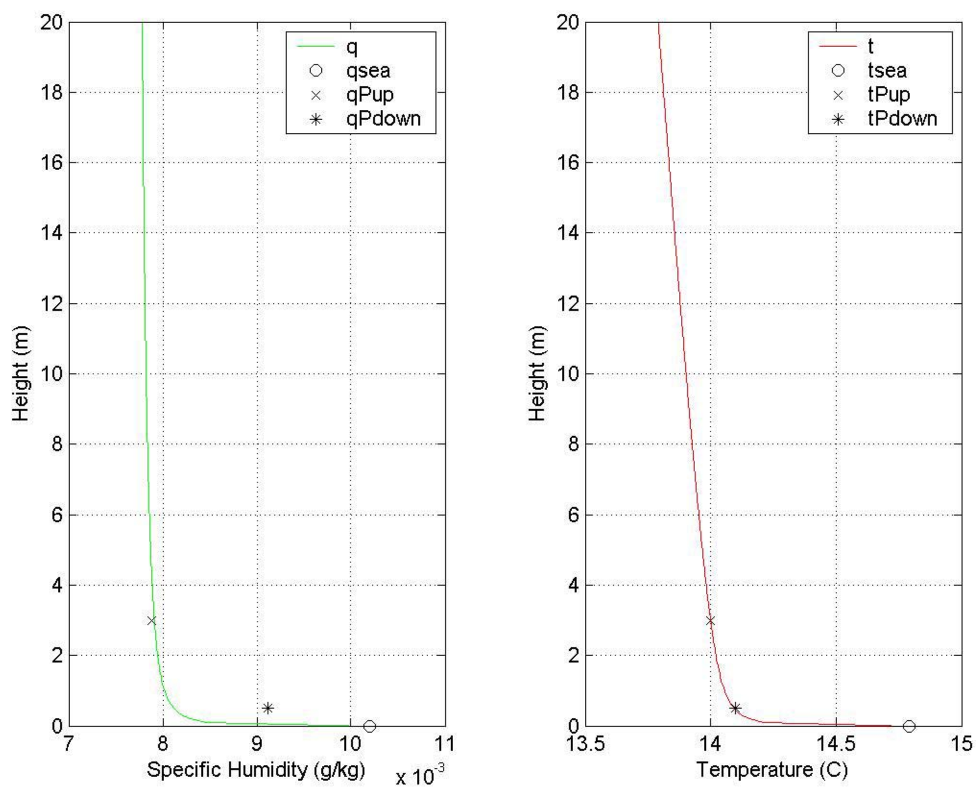

Figure 6. Vertical profiles of temperature and specific humidity calculated from Fig 5 input.

sonde positions (respectively) and are plotted against the theoretical vertical profile (Figure 6.). As seen previously, these values again are similar to those expected. This data set, however, emphasizes that even at 0.5 meters above the surface of the ocean we are only seeing a relative humidity of 91 to 92%. To get above 95% it would seem we would have to devise a means of taking measurements within the lowest 6 inches or so of the atmosphere.

Additional significance lies in the fact that the adjustment of pressure to the height of the sensor seems to lag behind the adjustment of relative humidity. Previously, pressure measurement was assumed to not have a lag time, which seems to be verified by Vaisala itself (Vaisala homepage). Vaisala denotes a lag time for relative humidity of 1 second, while none is listed for the pressure sensor (which has a resolution of 0.1mb, and a reproducibility of 0.5mb). This seems to indicate that pressure readings should be almost instantaneous and, thus, quickly climb and then level off. We obviously do not see this shown in this data. Either there is a lag time that Vaisala does not recognize, or the shelf life of these sensors is limited.

In the fourth data set (Figure 7.), also taken while aboard the RHIB, there is some correlation between pressure (height) and moisture content, but it is less striking than in the third data set. In this case we do not see the relationship begin to develop until the last half of the set (red rectangle). In addition, within this portion of the data we see a brief increase in temperature, which may slightly affect the relative humidity, but is countered by a rise in specific humidity as well. In this data set, the amplitude of the interrelated fluctuations is also smaller than that seen in the third data set.

When our “up” (A.) and “down” (B.) sonde points are chosen and plotted this time, we see some variation from the theoretic values (Figure 8.). Specific humidity is as expected, but the lower level temperature is three-tenths of a degree off of what was expected. This falls within the error range of the instrument, but may also be due to the

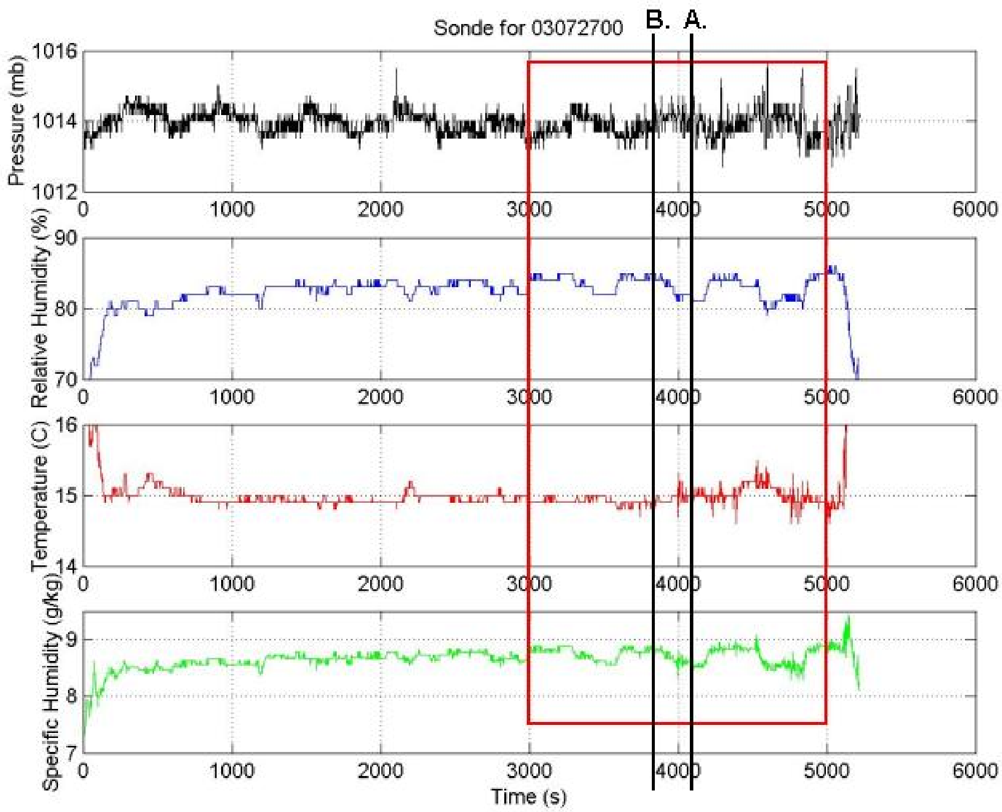

Figure 7. Rawinsonde data collected 27 July 2003 at 00Z.

presence of a slight inversion or more likely to a bad sea surface temperature (SST) value.

When looking at our results as a whole, it is clear that the best data is obtained when the sensor is located as close to the sea surface as possible. In our case this occurred aboard the RHIB. It was within these data sets that the expected, near saturation layer of the atmosphere just slightly above the ocean was sensed. Within this layer, pressure (height) changes correlated to large fluctuations in both relative and specific humidity. These results indicate, however, that this layer is not measured in meters, but in tenths of meters. Additionally, when winds are light, this layer is even thinner.

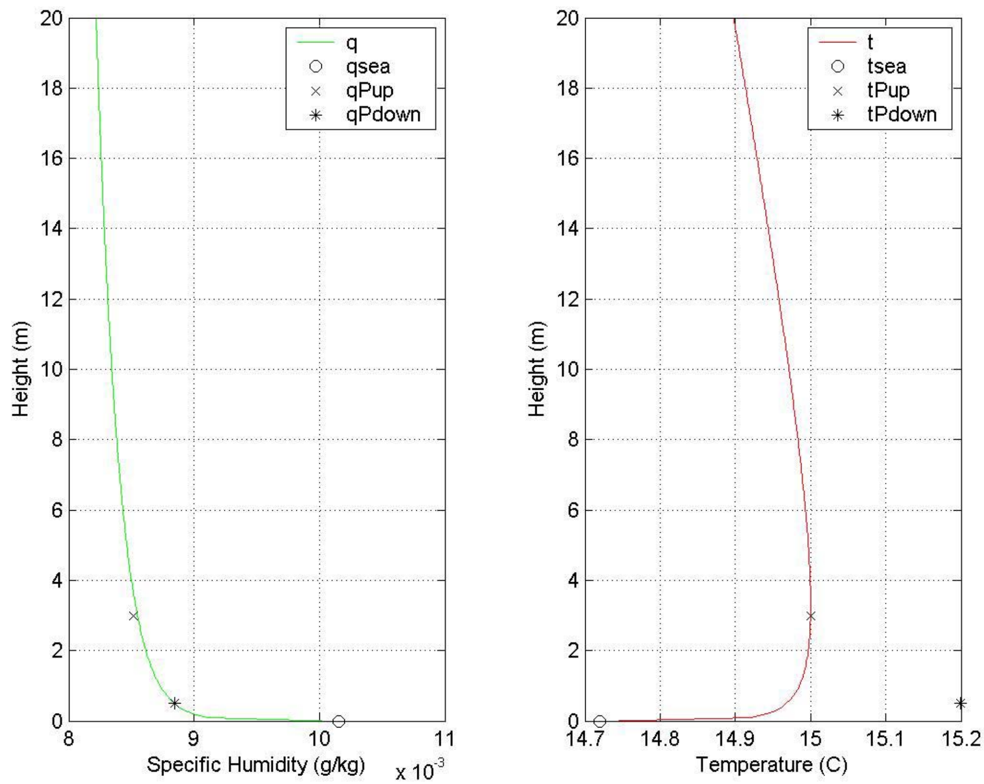

Figure 8. Vertical profiles of temperature and specific humidity calculated from Fig 7 input.

.

Recommendations:

If investigation into this area is to continue, several observations from this project may be helpful. First and foremost of these is that in order to observe this phenomenon, the rawinsonde must be located as close to the sea surface as possible. Measurements from a RHIB may be sufficient to accomplish this. Another idea may be to mount the sensor on a small foam float. This would allow it to bob along the ocean surface, but could only be done in a very light sea conditions, as it would be very vulnerable to splash and spray. Also, timekeeping during this evolution is vital. Problems resulting from time differences between different watches and clocks tend to compound and make reconstruction of the exact sequence of events during measurements difficult. Finally, in this experiment the length of time the sonde was in an “up” or “down” position was inadequate. Our duration was five minutes, and it would have been better if it was double or, preferably, triple that amount. This would give readings time to equilibrate and would allow for easier identification of the height of the sensor during analysis.

References:

1. Frederickson, P., evap_duct_model.m, June 1998-September 2000. Matlab program.
2. Frederickson, P., evap_duct_profile.m, June 1998-September 2000. Matlab program.
3. Frederickson, P., scaling_params.m, June 1998-September 2000. Matlab program.
4. Guest, P., ldsonde_d3.m, August 2003. Matlab program.
5. Guest, P., spec_hum.m. Matlab program.
6. Guest, P., stability_m.m. Matlab program.
7. Guest, P., stability_t.m. Matlab program.
8. Jordan, M., theta_q.m, October 1996. Matlab program.
9. Vorrath, J., plots.m, 2003. Matlab program.
10. http://www.vaisala.com is the Vaisala company home page.